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FUEL RESEARCH INSTITUTE OF SOUTH AFRICA.

TECHNICAL MEMORANDUM NO. 16 OF 1964.

A STUDY OF SOME ASPECTS OF THE SCALING OF COAL IN THE WORKINGS OF SOUTH AFRICAN COLLIERIES.

PROGRESS REPORT ON COAL MINING RESEARCH AT THE FUEL RESEARCH INSTITUTE.

BY:

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Coal is a fairly brittle substance, and size degradation unavoidably occurs to a greater or lesser extent during its winning, handling and transportation. The worst aspect of this degradation is the production of unwanted fines. Much thought has therefore been given to the development of mining, preparation and handling methods that will reduce the undesirable degradation to a minimum.

The present paper is, however, concerned with a different type of coal degradation which occurs not only in coal already broken from the seam but is also noted on exposed faces in the workings of collieries where it may cause dangerous working conditions. This degradation, leading to scaling of pillars or of coal or rock left in the roof or floor of workings is of particular significance in South Africa where bord and pillar mining is generally practiced and pillars must retain their strength so as to give adequate support to the overlying strata over long periods.

The coal in some coalfields or in particular seams appears to be more prone to this degradation than that from other fields or seams. The relative liability does not depend on the inherent friability of the coal, as

experience ..../

experience has shown that certain coal types that are hard and compact when freshly mined, may suffer more on exposure than other, relatively friable coal types do.

Inasmuch as this deterioration of the coal only occurs at exposed coal faces in colliery workings or in broken coal stored on the surface, this weakening of the coal has been ascribed to "weathering".

This is a rather wide term. In the present context it may be taken to describe the effect of one or more of the following processes: oxidation of organic and inorganic matter, the leaching out or deposition of minerals associated with coal as well as ion exchange that may occur as water percolates through the coal, the adsorption or desorption of water vapour or gases, temperature variations and microbiological action.

As in most naturally occurring processes, there is probably an interplay of various processes. This makes it all the more desirable to elucidate the overall process and to determine which are the more important causative factors. Such information will enable one to combat the degradative weathering more effectively.

This is one object of the present coal mining research done at the Fuel Research Institute.

SOME PROPERTIES OF SOUTH AFRICAN COALS:

Before discussing the possible effect of any of the above processes on the physical properties of coal, it is advisable to consider at least some of the characteristics of South African coals briefly.

General Remarks:

Since the following discussion is largely based on studies of "seam samples" it is advisable to mention, at the outset, that very few coal seams are uniform. Even a cursory examination of a coal face enables one to differentiate between obviously bright and dull coal occurring

either ..../

either as well developed distinct bands or seam sections or in more or less thin alternating bands, giving the coal a banded appearance (a greater number of petrographic components are recognised - but it is not the intention to discuss the petrographic composition of coal seams in this paper).

Furthermore, mineral inclusions as bands or concretions are generally present, and closer study reveals that mineral matter is also present in finely disseminated form in the coal substance. The amount of such finely distributed mineral matter is generally higher in South African coals than in, for example, the better European coals.

Although no extensive work has been done on the mineral matter in South African coal, the available evidence from chemical and x-ray work suggests that the definite stone bands (sandstone or shales) and concretions on the one hand, and the finely disseminated matter on the other hand, are composed, largely, of the same minerals. The main components are kaolinite, quartz, pyrite and calcite. Naturally, the proportions in which these minerals are present in any sample vary widely.

Although these individual petrological and mineralogical components would, because of their different physical and chemical properties, behave differently under various "weathering" conditions, most of the work to date has been done on seam samples, i.e., samples representing a seam or a seam section. In taking such samples a seam is usually (but not always) divided into sections according to visual appearance and obvious stone bands are generally excluded from "coal" samples. Even when seam sections are analysed one must consider the results to give an average overall picture of the coal or minerals present. Nevertheless, such average results serve a useful purpose and do reveal general characteristics.

RESULTS OF CHEMICAL ANALYSES:

Typical analyses done on coal samples from various coalfields are given in Table 1.

TABLE 1. ..../

TABLE 1.
TYPICAL ANALYSES OF SOUTH AFRICAN COALS.

Coalfield	Seam	Proximate Analysis % (air-dried-basis)				Ultimate Analysis % (Dry Ash-free basis)				
		Moisture	Ash	Vol. Mat.	Fix. Carb.	C	H	N	Org. S	O
VEREENIGING-O. F. S.										
Vierfontein	Main	7.8	21.5	23.2	47.5	78.9	4.4	2.0	0.6	14.1
Coalbrook No. 2.	2 & 3 Seams	5.5	28.1	21.7	44.7	78.8	4.3	1.9	0.3	14.7
Cornelia, Bertha No.1 Shaft		6.8	22.0	26.4	44.8	78.5	4.5	1.9	0.5	14.6
HEIDELBERG										
Springfield (Grootvlei) North Shaft	Upper	5.2	21.6	24.8	48.4	79.6	4.2	2.0	0.7	13.5
ERMELO										
Bellevue	C	4.1	14.8	31.1	50.0	80.3	5.0	2.1	0.5	12.1
WITBANK										
Brakfontein	2	4.6	13.3	29.4	52.7	81.0	4.8	2.0	0.5	11.7
Greenside	2 & 4	2.1	14.7	28.6	54.6	83.8	4.9	1.9	0.5	8.9
South Witbank.	4	3.5	20.2	27.1	49.2	81.4	4.6	2.0	0.6	11.4
NATAL										
Enyati	Alfred Gus Dundas Coking	1.4	14.1	17.8	66.7	88.5	4.5	2.2	0.5	4.3
Hlobane	Alfred Gus Dundas	1.3	16.2	19.6	62.9	88.5	4.5	2.0	0.5	4.5
Natal Navigation	Bottom	1.0	14.2	22.3	62.5	88.4	4.9	2.3	0.9	3.5

Applying the normal criteria (e.g., the air-dried or bed moisture content or the oxygen content - on dry-ash-free basis - to these results, it will be observed that the coal from the Vereeniging-Orange Free State-coalfield is the least mature (or of the lowest rank) of those listed, while some of the Natal coals are the most mature.

The coal from the Vereeniging-Orange Free State-coalfield is also characterised by a high ash content, and this is largely due to mineral matter intimately associated with the coal. This is apparent from the fact that no substantial reduction in ash content of this coal is achieved by normal coal cleaning methods even when working to a much higher discard than is normally considered economically bearable.

FINE STRUCTURE OF THE COAL AND NATURE OF THE COAL SURFACE:

Table 2 gives some information on the fine structure of South African coals. The results were obtained on samples of coal that had been crushed to pass a 60 B.S.S. sieve.

TABLE 2.

Details of the Pore Structure of Some Typical South African Coals.

Sample	Surface Area m^2/gm	Pore Volume cc/gm	Average Pore Radius Å
Orange Free State	131	0.176	19
Transvaal			
Witbank-Middelburg	128	0.125	20
Ermelo	161	0.130	12
Heidelberg	165	0.169	20
Natal	85	0.1	23

It .../

It will be noted that the less mature coals, such as those of the Vereeniging-Orange Free State coalfield have a higher porosity and a greater surface area. Accordingly, they have a greater capacity for gas as shown, for example, by the results given in Table 3.

TABLE 3.

Results of Oxygen Adsorption Data of Typical South African Coals.

Area	Per cent H_2O	Variation in oxygen adsorption in ml* at 30°C		at 60°C	
		Minimum	Maximum	Minium	Maximum
Natal	1.0-1.8	100	200	136	250
Witbank	1.5-2.3	150	290	300	380
South-eastern Witbank	2.0-3.0	220	370	415	660
Northern Witbank	2.2-2.5	170	200	325	390
Southern Witbank	2.6-5.0	190	550	303	770
Waterberg	2.8-3.5	105	200	325	390
Middelburg-Belfast	2.9-6.6	325	500	480	1,060
Orange Free State	3.7-6.8	280	350	520	690
Springs	3.9-6.0	425	700	650	1,140

Studies on the heat of adsorption (per molecule of oxygen adsorbed) indicated that for every coal the readily available surface had the same affinity for oxygen as the deeper, less accessible pore surfaces.

An even more striking result of this study was, however, that despite appreciable differences in the chemical composition, as indicated by the chemical analyses (e.g., the oxygen content of the coals) the surfaces of all the coals tested were, irrespective of their rank, remarkably uniform with respect to the ability to adsorb oxygen, in other words the amount of oxygen adsorbed per unit surface area of the coal (monolayer) could be considered constant throughout. Accepting this conclusion, one must further

conclude .../

*ml at N.T.P. adsorbed by 100 gm. of coal.

conclude e.g., with reference to the results quoted in Table 3, that the lower rank coals have a much greater accessible surface area than the more mature coals.

Notwithstanding this finding it could be shown in other studies, using thin, sound slabs of coal, that the permeability to gases, even of the lowest rank coals studied, was very low, being of the order of 10^{-13} cm^2/sec.

These studies of the fine structure of coals leads one to an interesting conclusion relevant to the subject of this paper, namely, that the penetration of gases or vapours into lumps of coal or a coal face must very largely be by way of cracks and fissures, as this rate would vastly exceed that of the diffusion of gases into the solid coal - even in the case of the lowest rank coal considered here. Alternatively, where penetration is only by way of diffusion into pores the depth of penetration after a given, reasonably short time is quite small at normal pressure or pressure differentials.

One result would be that any effect (e.g., expansion or rise in temperature) due to the adsorption or desorption of gases would as far as sound coal is concerned be largely limited to a relatively thin layer, and stresses, acting vertically to the exposed surface, may therefore arise.

Now few pieces of coal can be considered to be really sound and even the exposed coal face in the workings of a colliery is permeated by cracks and fissures, wide enough to provide access to gases. In such cracks any effect, such as expansion, due to the adsorption of gases into the adjacent sound solid coal would be doubled, and if a number of parallel cracks exist, the combined stress now parallel to the face may lead to rupture even if the stress at any one surface might be relatively low.

REVIEW OF SOME OTHER RELEVANT, EARLIER STUDIES:

1. Weathering of Coal:

It is known that some coals are more prone to "slacking" than others. The relative tendency to slack was studied at the Institute by exposing cobble coal samples

from .../

from various coalfields in shallow trays to the weather at Pretoria, for periods of up to one year.

The increase in friability was determined i.al. by subjecting portions of the samples to a drum-tumbler test after specific weathering periods. The results of such drum-tumbler tests on a number of samples after exposure for two weeks (crosses) and one year (rings) are shown graphically in Figure 1.

The results demonstrated that the lower rank coals were more liable to weathering although their friability in the relatively fresh state was lower than that of samples of higher rank coals.

2. The Reaction of Between Oxygen and Coal at Low Temperatures.

Much attention has been given to the reaction between coal and oxygen at the Institute even since its establishment in 1931, mainly because of the deterioration of coal quality due to oxidation and the possible occurrence of spontaneous combustion of coal stored in stacks.

Some of the results of these studies that are of interest here can be summarised as follows:

It was found, even when doing experiments on finely ground coal (-60 mesh B.S.S.) that the adsorption process is rapid initially, but continues for such a long time that it is practically impossible to obtain complete adsorption isotherms.

The heat generated was found to be of the order of 2.5 cal/m.l. O_2 throughout the process. The overall temperature rise during the initial rapid adsorption can be quite high, even in experiments on samples composed of large coal particles. One may therefore conclude that appreciable difference between the surface layer and the main mass of a coal particle can occur. The possible effect is discussed below:(Section on Thermal Expansion.)

It is fairly definitely accepted that surface complexes, stable up to temperatures of at least 40°C, are formed during the reaction at low temperatures (say 0°C to 40°C). Definite chemical compounds are finally formed, and as most of the reaction takes place in a surface layer, stresses may arise if these compounds should occupy a larger

volume .../

volume than the original compounds present in the coal.

3: Reaction of Oxygen with Mineral constituents of the Coal.

Evidence of the reaction of oxygen with minerals present in the coal seam can be found in the workings of every colliery and in stacks of coal exposed to the weather for some time. The most important reactant is probably pyrites (or marcasite if present). The consequent difference in volume between the volume of the oxidation products and the original compound may, as in the case of the formation of solid organic oxidation products, give rise to stresses in the coal that may cause rupture. Oxidation products formed (e.g., sulphuric acid) may also contribute to deterioration by reacting with other minerals (e.g., calcite) or man made structures (e.g., concrete).

4. Microbiological Action:

The full extent of the contribution by microbiological action in the deterioration of coal is not yet known. One effect that is becoming reasonably well established is that the presence of certain micro-organisms greatly promotes the oxidation of pyrites. Others may, possibly, attack the organic matter in the coal.

5. Leaching, Deposition of Minerals and Ion Exchange:

Although no systematic work has been done on the effect of these processes on the deterioration of South African coals, the matter may be considered briefly.

There are natural fissures in coal seams enabling water to seep through the coal even in the undisturbed bed. There is evidence of the deposition of minerals in such cracks (calcite, pyrites) and leaching is also possible. (The leaching out of oxidation products can frequently be observed.) Furthermore it is known that coal and some clay minerals have ion exchange properties; also, that ion exchange may cause clay minerals to expand. This property should still be effective even if the clay mineral is mixed with an organic coal substance.

The leaching out of minerals would weaken the structure as a whole, and would also tend to expose surfaces (e.g. to the effect of oxygen) that had been reasonably inaccessible before..

Consideration .../

CONSIDERATION OF THE DEGENERATIVE EFFECTS OF VARIOUS PROCESSES:

Considering the processes mentioned above, one can conclude that they may cause degradation in three ways, namely:

1. There may be a loss of strength because of the removal of constituents of the coal or seam; (for example, the leaching out of minerals or the loss of gas).
2. By causing stresses to arise because of temperature differences between one part of the coal and another.
3. By causing stresses to arise because of changes in volume (for example, swelling of clay minerals, or oxidation of pyrites).

1. Loss of Strength by Removal of Constituents:

It is not necessary to add to what has already been said about the leaching out of minerals.

Russian investigators report that the strength of coal is affected appreciably by the loss of gas. This aspect has not been studied to any extent in South Africa.

2. Thermal Expansion:

Most of the coal seams in South Africa occur at a relatively shallow depth below surface, the maximum being in the region of 800 feet. Rock temperatures are relatively low, and the possible cooling effect of the ventilation air in the workings will be neglected in this discussion.

The heat of adsorption of oxygen of coal has been found to be of the order of 65 kilo cal/mole of O_2 adsorbed. This is not large, but if the readily accessible surface is large, i.e., if a large volume of oxygen can be adsorbed during a relatively short period a fairly high local temperature rise may result.

The heat of adsorption of water vapour is appreciable and it could be shown that a temperature rise of up to 25°C could occur under certain circumstances when the relative humidity of the surrounding atmosphere was changed from 25% to 50%.(This would suffice to raise

the moisture .../

the moisture content of lower rank coals by 1%, and in fact greater changes in the "air-dry" moisture content occur frequently in practice with change in the weather.)

If one accepts that the penetration of gases or water vapour is low because of the low permeability of the coal, it is conceivable that the temperature rise will be confined to a surface layer only, and for some time at least, (depending on the thermal conductivity of the coal which is also low) there may be an appreciable temperature difference between the outer layer and the main mass of the coal.

No information is available on the thermal expansion of South African coal, but values of about 30×10^{-6} inch/inch per ^{o}C have been reported for English and Dutch coal. Accepting such a value and a temperature rise of, say, $25^{o}C$ a strain of $25 \times 30 \times 10^{-6}$ or 750 MI/I may be set up.

3. Changes in Volume:

The effect of changes in volume due to the formation of oxidation products occupying more space than the original compound is frequently observed in pyritic sandstones. In fact the oxidation of pyrites is probably a major cause of the disintegration of these sandstones. The effect is also observed in colliery workings where, for example, exposed sandstone or shale may disintegrate or scale off as a result of the oxidation of pyrites. The pyrites need not be present in concretions, finely disseminated pyrites may actually cause more harm.

Volume changes may also result from ion exchange reactions. Thus, it was reported recently that when certain ions replace others in an ion exchanger, changes in volume occur. As coal and some of the associated clay minerals have, at least, some ion exchange properties it is conveivable that ion exchange reactions may contribute to the degradation of coal.

However, the adsorption and desorption of gases and vapours may have a much greater effect.

Various clay minerals expand appreciably when they adsorb moisture and they would probably retain this property ..../

property when mixed with organic matter.

Some information on the expansion of British coal resulting from the adsorption of methanol was published by Bangham and some of his results are reproduced in Table 4. In terms of strain these figures represent values of the order of 16,500 MI/I which vastly exceeds that arising from temperature differences.

TABLE 4.

Expansion of Some British Coals Caused by the Adsorption of Methanol, (according to Bangham).

Sample No.	Saturation Expansion % Perpendicular to Bedding Plane
R1094	1.65
R839	1.67
R840	1.5
R271	7.57
R1014	7.9

No reference to similar work with water as adsorbant could be found in the available literature, but since water and methanol are similar in many respects (e.g., in polarity, surface tension, chemical structure) one may expect water to have a similar effect. Therefore expansion due to the adsorption of moisture might be a major cause of the disrupture of coal exposed to the atmosphere, especially if sudden changes in the relative humidity of the atmosphere occur.

THE RELATIVE HUMIDITY OF THE ATMOSPHERE IN THE SOUTH AFRICAN COALFIELDS.

The presently exploited South African coalfields of the Transvaal and the Orange Free State are situated on a high plateau and even those of Natal are at an appreciable height above sea level and sufficiently far removed from the sea to have an essentially high altitude, inland climate. There is, therefore, an appreciable

difference .../

difference between day and night temperatures, and while dew point may be reached at night the relative humidity of the air may be found to be low during the day.

Furthermore, the rainfall in these areas is of the order of 25 - 30 inches per annum, confined mainly to the summer season, and then very often to heavy storms (accompanied by a sharp drop in temperature) with intervening hot and dry spells.

Although average figures such as those shown in Table 5 would seem to indicate a rather stable situation, there are therefore drastic changes in the relative humidity of the atmosphere within a relatively short period of time, for example, practically 100% humidity at sunrise and relatively low temperature to some 20% relative humidity and temperature of some 22^{o}C at noon and probably 100% humidity just after a late afternoon storm.

(Such conditions of high humidity at relatively low temperature and low humidity at high temperature would be ideal for a cycle of adsorption and desorption of moisture on a porous substance.)

The effect of the relative humidity of the atmosphere can be observed when "air-drying" coals in laboratories in this region. With lower rank coals (bed moisture content, say, 9% and "air dried" moisture content of about 5%) it has been found that the air-dried moisture content, determined during rainy weather may be 2% to 3% higher than the value found when air-drying during a dry period. Higher rank coals, having air-dried moisture contents of 1.5 - 2.0% are not as sensitive to changes in the relative humidity of the atmosphere but a higher air-dried moisture content is found during rainy weather.

If the adsorption of moisture is accompanied by expansion or swelling (possibly thermal expansion as well as adsorption expansion) and such expansion should be localised to, say, the surface layers, it is obvious that stresses would arise that may contribute to the degradation of coal in storage on the surface.

To .../

To what extent such changes in the relative humidity of the atmosphere are transmitted to colliery workings by the ventilation air has not yet been established fully by the Institute. Existing data are being studied and further experimental work is being planned.

It has been reported, however, that in some collieries crackling of the coal can be heard in haulages when rainy weather occurs after a dry period. —

EXPERIMENTAL WORK:

(a) Introduction:

One may conclude from this survey that the adsorption or desorption of gases and moisture may affect the strength of coal.

Since little is apparently known about the magnitude of the possible expansion (or contraction) during adsorption (desorption) of moisture, a study of this problem was undertaken as part of the Institute's contribution to the "Safety in Mines" research programme.

TABLE 5.

Monthly Average of Daily Temperature and Relative Humidity during 1957 (Kindly made available by the S.A.Weatherbureau).

Month.	Ladysmith		Johannesburg	
	Rel.Humidity (%)	Temperature (°C)	Rel.Humidity (%)	Temperature (°C)
January	70	23.3	68	20.3
February	70	22.9	71	19.8
March	71	21.3	70	18.5
April	68	18.8	64	16.2
May	64	14.7	57	13.0
June	57	11.9	53	10.3
July	56	11.9	52	10.3
August	55	15.2	47	13.1
September	55	18.3	47	15.9
October	60	20.2	55	18.4
November	64	21.7	61	19.0
December	68	22.9	56	19.9

It was ..../

It was realised, at the outset, that the degree of disintegration that may result in adsorption-expansion (or swelling) will not be determined directly or only by the magnitude of the expansion or swelling. A number of factors, for example, the elastic properties of the coal and the extent to which expansion or swelling is localised, (for example, in concretions, specific mineral or petrographic components or in surface layers) thus giving rise to differential expansion and consequently strains, would affect the result.

However, it was considered essential to determine, first of all, what the magnitude of the expansion might be.

Drastic changes in the relative humidity of the surrounding atmosphere were frequently chosen, the better to determine small differences between coal types.

(b) Apparatus:

The extensometer, designed for this study, is shown schematically in Figure 2. It has been described in F.R.I. Technical Memorandum No. 2 of 1963, and it will therefore suffice to say here that its essential operating principle is that of the thin air wedge giving rise to an interference pattern when a beam of light passes through the optical system. The coal sample, with plane parallel surfaces, is placed in the apparatus relative to this optical system, so that any linear expansion or contraction changes the thickness of the wedge. Therefore, if a specific point above the wedge is observed, the visual effect of expansion or contraction is that bright or dark fringes pass across the field of vision, the passage of two consecutive bright lines across the field of vision representing an expansion (or contraction) of the coal equal to one half wave-length of the light used. The counting of bands was done automatically by a photo-multiplyer system and registered on a recorder.

The space around the sample is enclosed so that the atmosphere surrounding the sample can be controlled.

The system ..../

The system adopted is shown schematically in Figure 3. The vessel A represents the extensometer and C a vessel containing a saturated solution of a salt to maintain a definite water vapour pressure in the system.

The salts used and the relative humidities of the atmosphere obtainable therewith are given in Table 6.

TABLE 6.

Relative Humidities Attainable with Saturated Solutions At 20°C.

Salt	Relative Humidity %	Salt	Relative Humidity %
$Pb(NO_3)_2$	98	$Ca(NO_3)2.4\ H_2O$	54
$K_2\ CrO_4$	88	$K_2CO_3.\ 2\ H_2O$	43
$Na_2S_2O_3.5H_2O$	78	$Mg\ Cl_2.6\ H_2O$	34
$Na\ NO_2$	66	$KC_2\ H_3O_2.1\frac{1}{2}\ H_2O$	24
		$Zn\ Cl_2\ .\ 1\frac{1}{2}\ H_2O$	10
		Silica Gel	0

The atmosphere in the system was circulated by means of a small diaphragm pump B at a rate of 150 ml/minute. As the temperature of the laboratory was controlled to within approximately 1°C, constant humidity conditions could be maintained in the apparatus reasonably well for long periods.

(c) Preparation of Samples:

It was considered essential to use only specimens free from flaws such as cracks or inclusions in this study.

Although it would have been desirable to study the behaviour of various coal seam components, i.e. either petrographic or mineral components, separately, their isolation and preparation presents difficulties and it was therefore decided to confine the attention, at first to research on typical samples of coals from various coalfields. Most attention has so far been given to low rank coals.

The ..../

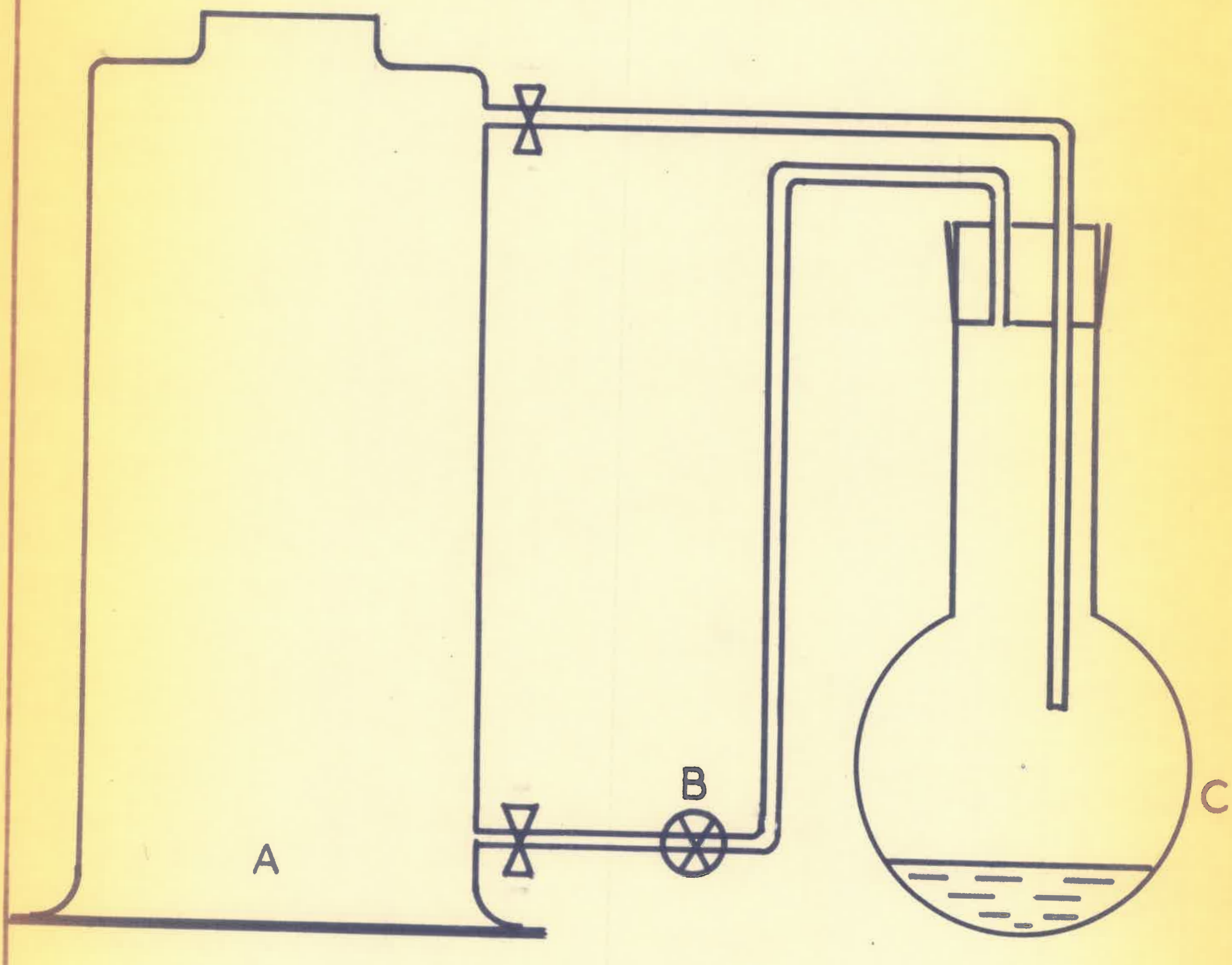

FIG. 3 THE SYSTEM FOR CONTROL OF THE HUMIDITY OF THE ATMOSPHERE SURROUNDING THE COAL SAMPLE

The samples taken at collieries consisted of fairly large lumps of coal and these were stored under water to minimise the effect of oxidation.

Blocks of approximately $\frac{3}{4}$"x$\frac{3}{4}$"x1" in size (with the large dimension perpendicular to the bedding plane) were first cut from such lumps with a diamond saw. These were examined under low magnification and all samples with visible flaws were rejected.

Sound specimens were then ground on a wet carborundum wheel to a rectangular prism shape, (e.g., $\frac{3}{4}$"x$\frac{3}{4}$"x1", the largest dimension "thickness" being perpendicular to the bedding plane). Finishing was done on a dry wheel. Later, prisms of $\frac{1}{5}$"x$\frac{1}{5}$"x1" were prepared and studied and finally slabs were cut from such prisms and ground to thicknesses of down to 0.01 inches, ($\frac{1}{5}$"x$\frac{1}{5}$"x0.01").

(e) Initial Experiments:

The initial experiments were done on samples of $\frac{3}{4}$"x$\frac{3}{4}$"x1" size, and the linear expansion or contraction parallel to the bedding plane was measured.

As the samples had been saturated under water, the contraction was usually measured while the relative humidity of the atmosphere surrounding the sample was kept at 0%.

Some of the results obtained on coal samples from the Vereeniging-Orange Free State coalfield are presented in Figure 4.

The results show clearly that the desorption is a very slow process under these conditions, probably because of the wellnigh impervious nature of sound coal, and the size of the specimen. Although equilibrium had probably not been attained after 80 hours the total contraction was of the order of 1,000 MI/I.

If, in fact, the long period was due to the slow rate at which moisture escaped from the inner parts of the specimen one might expect moisture gradients to exist in the specimen in the line of the dimension whose change of length was being measured. The observed contraction would then not present a true picture of contraction

in terms .../

in terms of the thickness of the specimen and the chosen change in the relative humidity conditions. If, due to the strain set up by such a differential desorption of water, cracks should develop parallel to the bedding plane, erroneous expansion values would also be obtained.

In order to minimise such moisture gradients and internal stresses it appeared advisable to use much thinner discs.

It was found that with slabs of 0.01 - 0.1 inch in thickness ($\frac{1}{5}$x$\frac{1}{5}$x0.1) equilibrium with the surrounding atmosphere - when changing the relative humidity from 0% to 100% - was attained in 1 to 10 hours, that is, the expansion reached a maximum value within this period. (This implies that it requires some 1 to 10 hours for saturation amount of moisture to pass through about 0.005 to 0.05 inches of coal in a direction parallel to the bedding plane.)

Some results obtained on thin discs are shown in Figure 5.

It is rather striking to observe that in these experiments the total expansion, expressed as a percentage of the original thickness was higher than the values obtained on the thick specimens. This difference may possibly be due to slower moisture penetration in the thick specimens.

The results in Figure 5 show that fairly consistent results were obtained on specimens representing the coal from Clydesdale (Coalbrook) Colliery, while those from the Vierfontein Colliery scattered appreciably. This coal was found to be rather more friable than the former. It was difficult to obtain reasonably sound specimens and to prepare them for the experiments. This property of the coal may account for the variation in the results (variance 25%).

Nevertheless, even the results on the Vierfontein coal suggest that uniform moisture conditions had probably been obtained throughout the coal at the end of the 8.00 hour period.

THE RELATION .../

THE RELATION BETWEEN THE AMOUNT OF MOISTURE ADSORBED AND THE EXPANSION.

Since the drastic change in the relative humidity chosen for the above experiments would hardly occur in practice, experiments were planned to determine the relation between the amount of moisture adsorbed and the expansion.

This can be done by allowing the coal specimens to attain equilibrium in an atmosphere of intermediate relative humidity. In these experiments the relative humidity of the atmosphere in the extensometer was kept at several intermediate values between 0% and 100%.

The study has not yet been completed but some of the results obtained are plotted in Figure 6. It will be noted that there is a linear relationship between the expansion and the prevailing relative humidity (or change of relative humidity.)

This may be interpreted as a linear relation between expansion or contraction and the amount of water adsorbed or desorbed.

The actual mass of moisture adsorbed when similar coal samples are subjected to similar changes in relative humidity is being determined separately, and the results will be reported later.

BEHAVIOUR OF COAL SAMPLES FROM DIFFERENT COAL SEAMS:

The coals studied so far may be characterised by the following typical rather than specific analyses.

TABLE 7.

Origin of Sample	Prox. Analysis (air-dried basis)				Porosity %	Surf. Area sq.m/g	Avg. Pore Size Å	Expansion %
	Moist. %	Ash %	Vol. Mat.%	Fix. Carb.%				
ORANGE FREE STATE								
Sigma	6.9	26.0	23.0	44.1	19.4	180	19	
Clydesdale	5.5	28.1	21.7	44.7	18.0	165	20	0.5-0.6
Vierfontein	7.8	21.5	23.2	47.5	18.0	161	15	0.9-1.2
WITBANK								
New Schoongezicht	2.3	11.7	25.5	60.5	13.8	110	21	0.3-0.4
NATAL								
D.N.C.	1.2	11.0	31.3	56.5	12.0	85	23	0.15-0.2
Northfield	1.0	13.5	22.7	62.8	9.7	59	21	0.1

CONCLUSIONS:

The experimental work described in this paper has already demonstrated that, where coal is allowed to expand or contract freely while adsorbing or desorbing moisture, the linear expansion perpendicular to the bedding plane is quite appreciable. In fact, it would be measurable by a less sensitive instrument than that used in these studies.

The rate of penetration of moisture (in the direction at right angle to the bedding plane) is low, being of the order of 0.005 inch/hr. at a total pressure of 1 atmosphere (partial pressure of water vapour at 100% humidity and 20°C). It might therefore appear at first sight as if only a thin surface skin might be involved. However, the rate of penetration may be much greater if cracks or fissures exist. Such cracks are present even in virgin coal and the strains arising as a result of differential expansion between the surface skin and deeper layers of coal may lead to further crack formation or the opening up or deepening of existing cracks which may result in a type of "chain " reaction involving an appreciable thickness of coal.

This conclusion adds weight to the following argument:

The coal "in situ" is generally under "bed moisture" conditions which implies a high degree or even complete saturation with moisture and possibly gases. The seam is wedged between rock formations and the coal is not free to expand.

In fact one may assume that during coalification the coal was compressed to the present seam thickness by the overlying strata and a condition was ultimately reached where the compression forces were balanced by resistance forces in the seam. This resistance force probably has various components of which the expansion force due to the presence of moisture and gas is certainly one.

Now, when a pillar is cut in the virgin seam an opportunity is given to the moisture and gas to escape. Any resulting thrust parallel to the bedding plane may be relieved by outbursts of gas and coal, but even if these

do not .../

do not take place, a layer of coal is depleted of gas and moisture. The layer thickness involved would probably depend originally on the number of existing cracks and fissures. The tendency would be for the coal to contract, and generally to have a lower vertical resistance force or thrust. The bearing power of the pillar is thereby reduced, that is, its effective cross-sectional area is reduced.

In a mined area where the roof is supported by pillars it appears that the distribution of stress by the overburden is such that the edge of pillars have to bear more stress than the central section.

If this is the case one may have the position that a section of the pillar which has been weakened by the depletion of moisture and gas is called upon to bear more than its share of total stress. The chances are that the coal in this layer may yield to the stress.

This line of argument accentuates the necessity to continue with the research on the effect of moisture and gas on the strength of coal.

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